REMARKS / ARGUMENTS

Please reconsider the application in view of the above amendments and the following remarks.

Disposition of Claims

Claims 1–40 are pending in this application. Claims 41–67 have been withdrawn in response to an earlier restriction requirement. Applicants retain the right to present claims 41–67 in a divisional application.

Claims 6–8, 23, and 27 have been amended to clarify the claims.

Rejection of Claims 6–9, 23 and 27–29 Under 35 U.S.C. § 112

Claims 6–9, 23 and 27–29 stand rejected under 35 U.S.C. § 112, second paragraph "for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention." Office Action Mailed Sept. 17, 2004 at 3, ¶ 8.

With respect to claims 6, 7, 23, and 27, the Examiner writes:

> Claims 6, 7, 23 and 27 are deemed indefinite as being drawn to an improper Markush grouping with respect to the recitation(s) "comprises a Portland cement . . . or a mixture thereof", and "comprise polyethylene, . . . and/or polystyrene particles" since the claim language "comprises" may include components or members outside of the listed species.

Id.

Applicants have amended claims 6, 7, 23, and 27, and respectfully request that the rejection of these claims under 35 U.S.C. § 112 be withdrawn. Applicants earnestly solicit a timely Notice of Allowance for these claims.

With respect to claims 8, 9, 28, and 29, which depend from claims 7 and 27, the Examiner writes:

> [these claims] are indefinite in view of the language "comprise", which fails to limit each claim to the recited species. Instead, the claim language should, e.g., read -- the inelastic lost circulation material particles are polyethylene particles -- .

Office Action Mailed Sept. 17, 2004 at 3–4, ¶ 8.

Applicants have amended claim 8 to depend from claim 1 rather than claim 7. Furthermore, the use of the transition word "comprise" in claim 8 as amended is proper. *See* MPEP § 2111.03 & 2173.01–.02 [8th ed. rev. 2, 2004]. The rejection of claim 9 is now moot because claim 9 depends from claim 8. Additionally, Applicants respectfully point out that claim 28 does not depend from a Markush-type claim. Accordingly, the use of "comprise" in claims 28 and 29 is proper. *See* MPEP § 2111.03, 2173.01–.02, 2173.05(h). Applicants respectfully request that the rejection of these claims under 35 U.S.C. § 112 be withdrawn, and earnestly solicit a timely Notice of Allowance for these claims.

With respect to claims 6 and 23, the Examiner writes:

> [I]t is not clear exactly what comprises "a high alkalinity cement". Thus amendment and/or clarification, e.g., is this an art-recognized term(?), is required.

Office Action Mailed Sept. 17, 2004 at 3, ¶ 8.

The term "high alkalinity cement" is an art-recognized term. The literature in the art often refers to certain cements as being highly alkaline, as may be discerned from inspection of the titles of, for example, the following references: Z. Owsiak, "Alkali-aggregate reaction in concrete containing high-alkali cement and granite aggregate," *Cem. Concr. Res.*, 34(1):7–11 (2004); J. Davidovits, "High-alkali cements for 21st century concretes," *Fr. Am. Concr. Inst., SP-144(Concrete Technology)*, 383–97 (1994); Yu. I. Benshtein, et al., "Evaluation of the effectiveness of silica additives added to high-alkaline cement for preventing internal corrosion

of concrete," *Zhurnal Prikladnoi Khimii*, 60(2):349–55 (1987). Because Applicants have provided evidence that the term "high alkalinity cement" is an art-recognized term, Applicants respectfully request that the rejection of claims 6 and 23 under 35 U.S.C. § 112 be withdrawn, and earnestly solicit a timely Notice of Allowance for these claims.

Rejections Under 35 U.S.C. § 102(b)

Claims 1–7, 17, 21–27, and 30 stand rejected under 35 U.S.C. 102(b) as being anticipated by U.S. Patent 5,736,594 ("Boles et al."). Office Action Mailed Sept. 17, 2004 at 4, ¶ 8. Applicants respectfully traverse, and assert that Boles et al. does not disclose all the features of the subject claims. Indeed, Applicants' independent claims 1 and 21 recite "inelastic lost circulation material particles," which are nowhere disclosed in Boles et al.

With respect to Boles et al., the Examiner writes:

> Boles et al. (note col. 1, lines 44-46; col. 2, lines 20-67) discloses a process of cementing a well utilizing a pumpable cementing slurry comprising a cement, water, other additives and a lost circulation agent comprising particles of ground-up recycled polystyrene. It is deemed that such polystyrene particles are inherently "inelastic", as called for in claims 1 and 20, insofar as polystyrene, per se, would normally be characterized as comprising a hard solid material. Moreover, the use of polystyrene particles is specifically recited in claims 7 and 27.

Office Action Mailed Sept. 17, 2004 at 4, ¶ 10.

Applicants respectfully submit that Boles et al. does not disclose a cement composition comprising "inelastic lost circulation material particles," as contemplated by the claims of the present invention; rather, Boles et al. discloses a cement composition that comprises "***expanded*** polystyrene," *see, e.g.*, U.S. Pat. No. 5,736,594 at col. 1, ll. 50, 52; *id.* col. 2, ll. 25, 60; *id.* col. 3, l. 43, and expanded polystyrene is an ***elastic*** material.

Expanded polystyrene is elastic because it has been expanded. When a plastic is expanded, pockets of air or gas are introduced into the plastic, which make the plastic light and spongy. *See* DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS 761 (6th ed. 2003); B. Chen & J. Liu, "Properties of lightweight expanded polystyrene concrete reinforced with steel fiber," *Cem. Concr. Res.*, 34:1259-63 (2004) ("Expanded polystyrene (EPS) is *a kind of stable foam* with low density, consisting of discrete air voids in a polymer matrix." (emphasis added)). (Courtesy copies of the two preceding references are enclosed for the convenience of the Examiner.)

Further evidence that expanded polystyrene is elastic is its small modulus of elasticity—expanded polystyrene is over 1,000 times more elastic than non-expanded polystyrene. *Compare* Physical Properties of EPS, at http://www.benchmarkfoam.com (indicating that the modulus of elasticity for Type I expanded polystyrene is **180 psi**), *with* ALBIS MIPS 05A13A polystyrene, MatWeb Material Property Data at http://www.matweb.com (indicating that a natural, unreinforced polystyrene used in applications such as plastic containers has a modulus of elasticity of **320,538 psi**). (Courtesy copies of the two preceding references are enclosed for the convenience of the Examiner.)

Because Boles et al. nowhere discloses the use of inelastic particles in a cement composition, but rather discloses elastic particles, Boles et al. does not disclose "inelastic lost circulation material particles." Therefore, Boles et al. does not anticipate all of the limitations of independent claims 1 and 21 as required by 35 U.S.C. §102. Accordingly, Applicants respectfully request withdrawal of the rejection under 35 U.S.C. § 102(b) against claims 1 and 21, as well as the dependent claims 2-7, 17, 22–27, and 30, and earnestly solicit the timely issuance of a Notice of Allowance for these claims.

Rejections Under 35 U.S.C. § 103(a) in View of Boles et al.

Claims 3, 4, 10, 11, 15, 16, 18, 19, 25, 26, 31–34, and 38–40 stand rejected under 35 U.S.C. 103(a) as being unpatentable over Boles et al. Office Action Mailed Sept. 17, 2004 at 5, ¶ 13. Applicants respectfully traverse, and assert that Boles et al. does not teach or suggest a cement composition comprising "inelastic lost circulation material particles," as required by the subject claims.

A prima facie case of obviousness requires a showing that all of the claim limitations of the rejected claims are taught or suggested by the prior art. MPEP § 2143 & 2143.03. Here, because Boles et al. neither teaches nor suggests "inelastic lost circulation particles," Boles et al. does not teach or suggest all the elements of Applicants' claims, and thus a prima facie case of obviousness cannot be established based upon the Boles et al. reference.

Each of the rejected claims recites a limitation of "inelastic lost circulation material particles." Boles et al. does not suggest or disclose this element, but rather discloses cement compositions that include "ground-up recycled expanded polystyrene," Boles et al., col. 2, ll. 59–60, which, as Applicants have shown, is an elastic, rather than inelastic, material. Boles et al. nowhere suggests or discloses the use of inelastic particles as a lost circulation material.

Thus, Boles et al. does not teach or suggest all the elements of Applicants' invention, and consequently, cannot form a basis for a 35 U.S.C. § 103(a) rejection against Applicants' claims. Accordingly, Applicants respectfully request withdrawal of the rejection under 35 U.S.C. § 103(a) against claims 3, 4, 10, 11, 15, 16, 18, 19, 25, 26, 31–34, and 38–40, and earnestly solicit the timely issuance of a Notice of Allowance for these claims.

Rejections Under 35 U.S.C. § 103(a) in view of KWIK-SEAL Brochure and Boles et al.

Claims 12–14 and 35–37 stand rejected under 35 U.S.C. 103(a) as being unpatentable over Boles et al in further view of the Halliburton Brochure "KWIK-SEAL Lost Circulation Additive." Office Action Mailed Sept. 17, 2004 at 6, ¶ 14. Even when combined, these references do not suggest or disclose the use of inelastic particles as a lost circulation material. Accordingly, Applicants respectfully request withdrawal of the rejection under 35 U.S.C. § 103(a) against claims 12–14 and 35–37, and earnestly solicit the timely issuance of a Notice of Allowance for these claims.

SUMMARY

In light of the above remarks and amendments, Applicants respectfully request reconsideration and withdrawal of the outstanding objections and rejections. Applicants further submit that the application is now in condition for allowance, and earnestly solicit timely notice of the same. Should the Examiner have any questions, comments or suggestions in furtherance of the prosecution of this application, the Examiner is invited to contact the attorney of record by telephone, facsimile, or electronic mail.

Applicants believe that there are no fees due in association with this filing of this Amendment and Response. However, should the Commissioner deem that any fees are due, including any fees for extensions of time, Applicants respectfully request that the Commissioner accept this as a Petition Therefor, and direct that any additional fees be charged to Baker Botts L.L.P. Deposit Account No. 02-0383, Order Number 063718.0513.

Respectfully submitted,

Baker Botts L.L.P.

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McGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS

Sixth Edition

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On the cover: Representation of a fullerene molecule with a noble gas atom trapped inside. At the Permian-Triassic sedimentary boundary the noble gases helium and argon have been found trapped inside fullerenes. They exhibit isotope ratios quite similar to those found in meterorites, suggesting that a fireball meteorite or asteroid exploded when it hit the Earth, causing major changes in the environment. ***(Image copyright © Dr. Luann Becker. Reproduced with permission.)***

Over the six editions of the Dictionary, material has been drawn from the following references: G. M. Garrity et al., *Taxonomic Outline of the Procaryotes,* Release 2, Springer-Verlag, January 2002; D. W. Linzey, *Vertebrate Biology,* McGraw-Hill, 2001; J. A. Pechenik, *Biology of the Invertebrates,* 4th ed., McGraw-Hill, 2000; *U.S. Air Force Glossary of Standardized Terms,* AF Manual 11-1, vol. 1, 1972; F. Casey, ed., *Compilation of Terms in Information Sciences Technology,* Federal Council for Science and Technology, 1970; *Communications-Electronics Terminology,* AF Manual 11-1, vol. 3, 1970; P. W. Thrush, comp. and ed., *A Dictionary of Mining, Mineral, and Related Terms,* Bureau of Mines, 1968; *A DOD Glossary of Mapping, Charting and Geodetic Terms,* Department of Defense, 1967; J. M. Gilliland, *Solar-Terrestrial Physics: A Glossary of Terms and Abbreviations,* Royal Aircraft Establishment Technical Report 67158, 1967; W. H. Allen, ed., *Dictionary of Technical Terms for Aerospace Use,* National Aeronautics and Space Administration, 1965; *Glossary of Stinfo Terminology,* Office of Aerospace Research, U.S. Air Force, 1963; *Naval Dictionary of Electronic, Technical, and Imperative Terms,* Bureau of Naval Personnel, 1962; R. E. Huschke, *Glossary of Meteorology,* American Meteorological Society, 1959; *ADP Glossary,* Department of the Navy, NAVSO P-3097; *Glossary of Air Traffic Control Terms,* Federal Aviation Agency; *A Glossary of Range Terminology, White Sands Missile Range, New Mexico,* National Bureau of Standards, AD 467-424; *Nuclear Terms: A Glossary,* 2d ed., Atomic Energy Commission.

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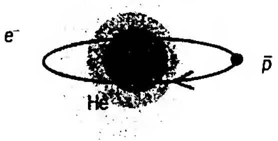
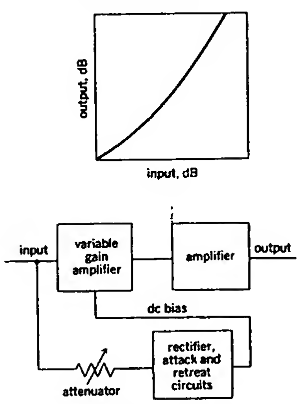
EXOTIC ATOM



Schematic diagram of an antiprotonic helium atom, with an electron (e^-) cloud around the helium nucleus (He^{++}), and an antiproton ($\bar{p}$) in orbit.

EXPANDER



Input-output characteristics and schematic block diagram of an expander.

certain invertebrates, such as arthropods. [VERT ZOO] Bony or horny epidermal derivatives, such as nails, hoofs, and scales. { ¦ek·sō'skel·ə·tən }

exosmosis [PHYSIO] Passage of a liquid outward through a cell membrane. { ¦ek·sō·äs'mō·səs }

exosphere [METEOROL] An outermost region of the atmosphere, estimated at 300–600 miles (500–1000 kilometers), where the density is so low that the mean free path of particles depends upon their direction with respect to the local vertical, being greatest for upward-traveling particles. Also known as region of escape. { 'ek·sō,sfir }

exospore [MYCOL] An asexual spore formed by abstriction, as in certain Phycomycetes. { 'ek·sō,spȯr }

exosporium [BOT] The outer of two layers forming the wall of spores such as pollen and bacterial spores. Also known as exine. { ,ek·sə'spȯr·ē·əm }

exostome [BOT] The opening through the outer integument of a bitegmic ovule. { 'ek·sə,stōm }

exostosis [MED] A benign cartilage-capped protuberance from the surface of long bones but also seen on flat bones, caused by chronic irritation as from infection, trauma, or osteoarthritis. { ,ek·sə'tō·səs }

exotheca [INV ZOO] The tissue external to the theca of corals. { ,ek·sə'thē·kə }

exotherm [CHEM ENG] The graphical plotting of heat rise and fall versus time for an exothermic reaction or process system. { 'ek·sə,thərm }

exothermic [PHYS] Indicating liberation of heat. Also known as exoergic. { ¦ek·sō'thər·mik }

exotic [ECOL] Not endemic to an area. { ig'zäd·ik }

exotic atom [ATOM PHYS] A system in which either the proton that forms the nucleus of a hydrogen atom is replaced by another particle (such as a muon, to form muonium, or a positron, to form positronium), one electron in an ordinary atom is replaced by another particle (such as a muon, pion, or antiproton), or both substitutions are made (as in antihydrogen). { ik¦säd·ik 'ad·əm }

exotic four-space [MATH] A four-dimensional manifold that is homeomorphic, but not diffeomorphic, to four-dimensional Euclidean space. { ig¦zäd·ik 'fȯr,spās }

exotic fuels [MATER] The hydroborons which have higher calorific values than do the carbon-hydrogen fuels, once proposed as high-energy fuels for aircraft and missiles; include borane (BH_3), borobutane (B_4H_{10}), and borodecane ($B_{10}H_{14}$). { ig'zäd·ik 'fyülz }

exotic nucleus [NUC PHYS] An atomic nucleus in which the ratio of neutron number to proton number is much larger or much smaller than that of naturally occurring nuclei. { ig'zäd·ik ¦nü·klē·əs }

exotic sphere [MATH] A smooth manifold that is homeomorphic, but not diffeomorphic, to a sphere. { ig¦zäd·ik 'sfir }

exotic stream [HYD] A stream that crosses a desert as it flows to the sea, or any stream which derives most of its water from the drainage system of another region. { ig'zäd·ik 'strēm }

exotic viral disease [MED] A viral disease that occurs only rarely in human populations of developed countries. { ig¦zäd·ik ¦vī·rəl diz,ēz }

exotoxin [MICROBIO] A toxin that is excreted by a microorganism. { ¦ek·sə¦täk·sən }

exozodiacal dust [ASTRON] Dust that appears to be orbiting within a few astronomical units of a star and may be analogous to the zodiacal dust in the solar system. { ,ek·sō·zō,dī·ə·kəl 'dəst }

expandable space structure [AERO ENG] A structure which can be packaged in a small volume for launch and then erected to its full size and shape outside the earth's atmosphere. { ik¦span·də·bəl 'spās ,strək·chər }

expanded batch [COMPUT SCI] A level of computer processing more complex than basic batch, in which computer programs perform complex computations and produce reports that analyze performance in addition to reporting it. { ik'spand·əd 'bach }

expanded clay [MATER] A material made from common brick clays by grinding, screening, and then feeding through a gas burner at about 2700°F (1482°C), thus changing the ferric oxide to ferrous oxide and causing the formation of bubbles. { ik'spand·əd 'klā }

expanded-flow bin [ENG] A bin formed by attaching a mass-flow hopper to the bottom of a funnel-flow bi… { ik¦spand·əd 'flō ,bin }

expanded foot [HYD] A broad, bulblike or fan-shaped … mass formed where a valley glacier flows beyond its confini… walls and extends onto an adjacent lowland at the bottom … a mountain slope. { ik'spand·əd 'fu̇t }

expanded metal [MET] An alloy which has expanded fo… lowing cooling and solidification. { ik'spand·əd 'med·əl }

expanded notation [MATH] The representation of a numb… as the sum of a series of terms, each of which is writ… explicitly as the product of a digit and the base of the numb… system raised to some power. { ik¦spand·əd nō'tā·shən }

expanded numeral [MATH] A number expressed … expanded notation. { ik¦spand·əd 'nüm·rəl }

expanded perlite [MATER] Perlite that has been fine… ground and subjected to extreme heat, causing the particles … become considerably expanded and porous because of relea… of water. { ik'spand·əd 'pər,līt }

expanded plastic [MATER] A light, spongy plastic made b… introducing pockets of air or gas. Also known as foame… plastic; plastic foam. { ik'spand·əd 'plas·tik }

expanded position indicator display [ELECTR] Display o… an expanded sector from a plan position indicator presentation… { ik'spand·əd pə'zish·ən ¦in·də,kad·ər di,splā }

expanded scope [ELECTR] Magnified portion of a give… type of cathode-ray tube presentation. { ik'spand·əd 'skōp }

expanded slag [MATER] Slag formed by running slag from… phosphate rock onto a forehearth at about 2000°F (1093°C)… and then treating it with water, high-pressure steam, and air… used to make lightweight concrete blocks. { ik'spand·əd 'slag }

expanded sweep [ELECTR] A cathode-ray sweep in which… the movement of the electron beam across the screen is speeded… up during a selected portion of the sweep time. { ik'spand·əd 'swēp }

expander [ELECTR] A transducer that, for a given input… amplitude range, produces a larger output range. { ik'spand·ər }

expander flange [ENG] A type of butt-welded flange designed with a tapered bore so that various pipe sizes can be matched. { ik'span·dər ,flaŋ }

expanding [MET] A process used to increase the inside diameter of a hollow piece, such as a tube, cup, or shell. { ik'spand·iŋ }

expanding arm [ASTRON] A spiral arm of the Galaxy consisting of neutral hydrogen that lies between 2.5 and 4 kiloparsecs beyond the galactic center and is moving out from it at about 85 miles (135 kilometers) per second. { ik'spand·iŋ 'ärm }

expanding brake [MECH ENG] A brake that operates by moving outward against the inside rim of a drum or wheel. { ik'spand·iŋ 'brāk }

expanding population [ECOL] A population containing a large proportion of young individuals. { ik'spand·iŋ ,päp·yə'lā·shən }

expanding square search *See* square search. { ik¦spand·iŋ ¦skwer ¦sərch }

expanding universe [ASTROPHYS] Explanation of the red shift observed in spectral lines from distant galaxies as due to a mutual recession of galaxies away from each other. [RELAT] A model of the universe describing the process defined in the astronomy definition, in which the universe is nonstatic, homogeneous, and isotropic; based on Einstein's field equations with a nonvanishing cosmical constant. { ik¦spand·iŋ 'yü·nə·vərs }

expandor [ELECTR] The part of a compandor that is used at the receiving end of a circuit to return the compressed signal to its original form; attenuates weak signals and amplifies strong signals. { ik'spand·dər }

expansion [ELECTR] A process in which the effective gain of an amplifier is varied as a function of signal magnitude, the effective gain being greater for large signals than for small signals; the result is greater volume range in an audio amplifier and greater contrast range in facsimile. [MATH] The expression of a quantity as the sum of a finite or infinite series of terms, as a finite or infinite product of factors, or, in general, in any extended form. [MECH ENG] Increase in volume of working material with accompanying drop in pressure of a gaseous or vapor fluid, as in an internal combustion engine or

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CEMENT AND CONCRETE RESEARCH

Communication

Properties of lightweight expanded polystyrene concrete reinforced with steel fiber

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Abstract

Expanded polystyrene (EPS) concrete is a lightweight, low strength material with good energy-absorbing characteristics. However, due to the light weight of EPS beads and their hydrophobic surface, EPS concrete is prone to segregation during casting, which results in poor workability and lower strength. In this study, a premix method similar to the 'sand-wrapping' technique was utilized to make EPS concrete. Its mechanical properties were investigated as well. The research showed that EPS concrete with a density of 800–1800 kg/m^3 and a compressive strength of 10–25 MPa can be made by partially replacing coarse and fine aggregate by EPS beads. Fine silica fume greatly improved the bond between the EPS beads and cement paste and increased the compressive strength of EPS concrete. In addition, adding steel fiber significantly improved the drying shrinkage.

Keywords: Concrete; Fiber reinforcement; Silica fume; Compressive strength; EPS

1. Introduction

Expanded polystyrene (EPS) is a kind of stable foam with low density, consisting of discrete air voids in a polymer matrix. The polystyrene beads can easily be incorporated in mortar or concrete to produce lightweight concrete, with a wide range of densities [1]. The research on EPS concrete can be traced back to 1973, when Cook [2] investigated EPS as an aggregate for concrete. Now, EPS lightweight concrete can be used in varied structural elements such as cladding panels, curtain walls, composite flooring systems, load-bearing concrete blocks, the subbase material for a pavement, floating marine structures, etc. [3–7]. Especially, it can be used within the protective layer of a structure for impact resistance due to its good energy-absorbing characteristics [8].

However, polystyrene beads have two disadvantages that constrains the application and popularization of EPS concrete: (1) they are extremely light, with a density of only 12 to 20 kg/m^3, which can cause segregation in mixing, and (2) they are hydrophobic. Hence, chemical treatment of its surface is needed. In previous reports, some bonding additives were suggested, such as epoxy resin or aqueous dispersions of polyvinyl propionate [3–6]. However, these are costly. In addition, EPS concrete in these reports was within very low strength range.

Therefore, in this study, a type of fiber-reinforced concrete with EPS light aggregates was developed, with up to 20 MPa design strength. Fine silica fume, instead of bonding additives, was used to improve the dispersion of EPS in the cement paste and the interfacial bonding strength. The effects of different volume contents of EPS on the strength and shrinkage were investigated as well.

2. Experimental details

2.1. Materials and mix proportions

The materials used in this study were ordinary Portland cement conforming to BS12: 1991, river sand with a fineness modulus of 2.85, crushed granite with a maximum size of 20 mm, silica fume, and steel fibers with length of 25 mm and aspect ratio of 60. Two types of commercially available spherical EPS beads that are essentially single-

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Table 1
Details of EPS concrete mixes containing steel fiber

Series	Mix number	Cement (kg/m³)	Silica fume (%)	Water (kg/m³)	Gravel (kg/m³)	Sand (kg/m³)	EPS (kg/m³)		% Volume of EPS	Steel fiber (kg/m³)	Superplasticizer (ml/kg of cement)
							Type A	Type B			
Series I	1	472	–	175	1133	620	–	–	–		4.0
	2	472		175	710	392	1.75	0.74	25	–	4.2
	3	472		175	710	392	1.75	0.74	25	70	4.2
	4	472		175	455	255	2.8	2.21	40		4.5
	5	472		175	455	255	2.8	2.21	40	70	4.5
	6	472		175	201	118	3.85	3.03	55		5.1
	7	472		175	201	118	3.85	3.03	55	70	5.1
Series II	8	425	10	175	1133	620	–	–		–	4.0
	9	425	10	175	710	392	1.75	0.74	25	0	4.2
	10	425	10	175	710	392	1.75	0.74	25	70	4.2
	11	425	10	175	455	255	2.8	2.21	40	0	4.5
	12	425	10	175	455	255	2.8	2.21	40	70	4.5
	13	425	10	175	201	118	3.85	3.03	55	0	5.1
	14	425	10	175	201	118	3.85	3.03	55	70	5.1

sized (Types A and B) were used. The grading shows that Type A has mostly 3.0-mm-size beads and Type B has mostly 8.0-mm-size beads. The bulk density was 20 kg/m³ for Type A and 8.5 kg/m³ for Type B. A naphthalene-based superplasticizer was used to produce the mixes a flowable or highly workable nature, to suit the hand compaction adopted. The complete details of the concrete mixes are presented in Table 1.

2.2. Mixing of EPS concrete

Concrete was mixed in a planetary mixer of 30-l capacity. A technique similar to 'sand-wrapping' was applied on the EPS beads. EPS beads were wetted initially with 30% of the mixing water and superplasticizer before adding the remaining materials. Mixing was continued until a uniform and flowing mixture was obtained. The fresh concrete was then poured into molds and compacted by hand.

2.3. Casting, curing and testing of concrete specimens

A number of standard test specimens of different sizes were chosen for investigating the various parameters. Cubes of 150-mm size were used for studying the compressive strength at 3, 7, 14, 28, and 60 days. Split tensile strength tests were conducted on cubes of 100 mm. Prisms of 100 × 100 × 515 mm were used for shrinkage testing at 3, 7, 14, 28, and 60 days.

From each batch, 15 cubes of 150-mm size, three cubes of 100 mm and three 100 × 100 × 515 mm prisms were cast. The specimens were stripped approximately 24 h after casting and were placed in a fog room (95 ± 3% RH, 22 ± 2 °C). For shrinkage testing, after the specimens were cured in the fog room for 23.5 ± 0.5 h, the specimens were demolded, placed in a controlled testing condition (RH >60%, 20 ± 3 °C), and immediately measured to get initial values. After that, the specimens were returned to the curing room, and then taken

Table 2
Strength and density of EPS concrete mixes

Series	Mix number	Fresh concrete density (kg/m³)	Compressive strength (MPa)					Split tensile density (kg/m³)
			3 days	7 days	14 days	28 days	60 days	
Series I	1	2435	25.4	44.2	54.6	59.2	60.0	8.70
	2	1820	9.0	16.5	20.3	22.1	22.2	2.31
	3	1883	8.6	15.9	19.3	21.4	21.3	2.62
	4	1356	7.4	12.6	16.5	17.6	17.4	2.14
	5	1403	6.9	11.7	15.6	16.7	16.8	2.53
	6	876	4.3	7.6	9.8	10.6	10.6	1.32
	7	910	4.0	7.3	8.9	9.9	10.0	2.08
Series II	8	2440	33.5	54.0	63.6	68.3	68.2	9.70
	9	1850	12.3	20.0	24.4	25.7	25.6	2.4
	10	1929	12.6	21.1	25.0	25.9	26.0	2.73
	11	1370	8.1	13.2	18.4	20.1	20.2	2.22
	12	1415	8.6	13.7	18.7	20.8	20.7	2.68
	13	882	4.9	8.1	10.1	11.3	11.5	1.73
	14	892	4.9	8.0	9.8	10.9	11.0	2.31

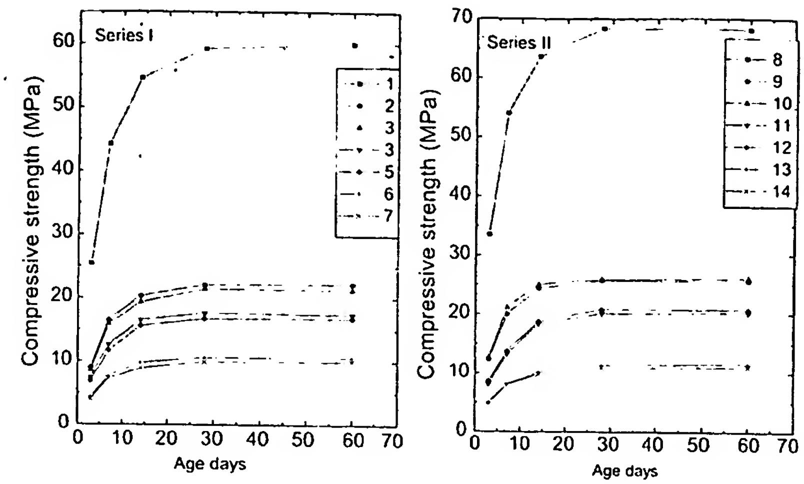

Fig. 1. Compressive strength versus time for Series I and Series II mixes.

out and tested at the appropriate testing ages. After the water on the surface of each specimen was wiped off with a damp cloth, the length change was measured and the shrinkage strain was calculated according to ASTM C490–93a. Compressive strength tests were carried out in a testing machine of 2000 kN capacity, at a loading rate of 2.5 KN/s. The split tensile strength test was conducted on cubes at 28 days, according to ASTM C 496–89.

3. Results and discussion

A comprehensive summary of EPS concrete with different strengths and plastic densities of all the concretes is presented in Table 2.

3.1. Compressive strength

3.1.1. Effect of age

Fig. 1 shows the development of compressive strength with the age for EPS concrete. The compressive strength of EPS concrete in almost all mixes displayed a continuous increase with age. The rate of strength development was greater initially and decreased as the age increased. However, a comparison of strengths at 7 days revealed that concretes with no silica fume developed almost 70–75% of its 28-day strength, while those containing silica fume developed almost 85–90% of the corresponding 28-day strength. Comparison of the strength at 28 and 60 days indicated that at those ages, all mixes, except Mix 1, showed no appreciable improvement in compressive strength with age.

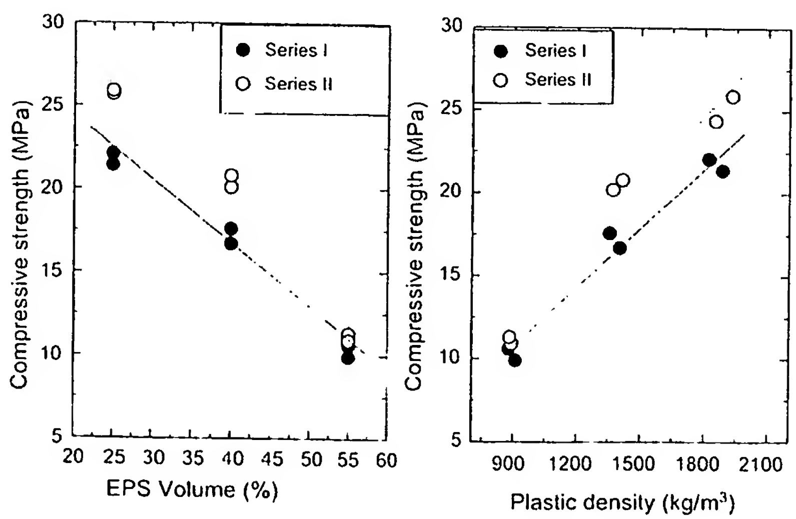

Fig. 2. Variation of strength with EPS volume and density

3.1.2. Effect of density and EPS volume

The compressive strengths of EPS concretes with different plastic densities of concrete and the volume content of EPS are presented in Fig. 2. The strength of EPS concrete appeared to increase linearly with an increase in concrete density, or with a decrease in the EPS volume, which is consistent with the results from Ref. [6]. The plastic density of normal concrete with a compressive strength of 59.2 MPa was 2435 kg/m^3. As for EPS concrete, when its plastic density was 75%, 55%, and 35% of that of normal concrete, its strength was 35%, 30%, and 20% of that of normal concrete, respectively. Therefore, a lightweight material that can provide up to 30 MPa of strength and only 70% of the density of normal concrete is available by using EPS with different sizes to partially replace coarse and fine aggregate.

In addition, the failure mode of EPS concrete under compression is different from that of normal concrete. The failure was observed to be more gradual (more compressible), and the specimens were capable of retaining the load after failure, without full disintegration. This clearly indicated the high energy absorption capacity of EPS concrete that was reported earlier [6]. Therefore, EPS concrete may be considered for mitigating vibration.

3.1.3. Effect of silica fume and steel fiber

Fig. 3 illustrates the effects of fine silica fume and steel fiber on the compressive strength of EPS concrete. It can be seen that with the same volume content of EPS, fine silica fume can significantly increase compressive strength (at most, up to around 15%), which indicated that fine silica fume can improve the dispersion of EPS in the cement paste and interfacial bonding between EPS and cement paste. However, with an increasing content of EPS, the increase was reduced. When the volume content of EPS was 55%, the compressive strength increased only around 8%. Therefore, at an appropriate content, silica fume can replace some special bonding agents to improve the strength of EPS concrete.

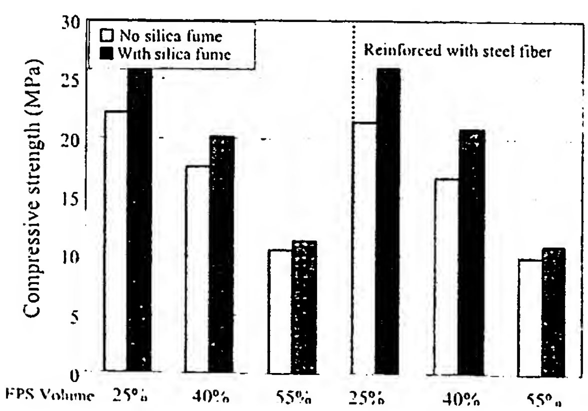

Fig. 3. Effect of silica fume on the compressive strength of EPS concrete.

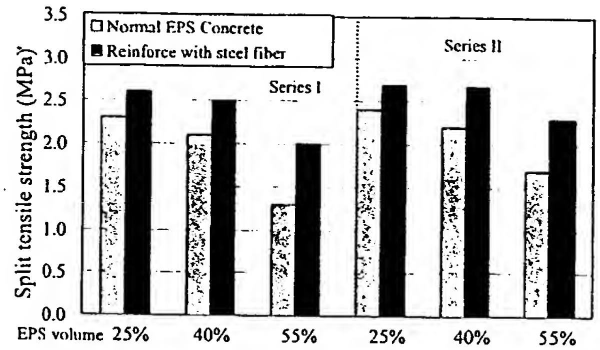

Fig. 4. Variation of split tensile strength with EPS volume.

3.2. Split tensile strength

Fig. 4 displays the effect of steel fibers on the split tensile strength of EPS concrete with different EPS contents. Steel fibers greatly increased the split tensile strength of EPS concrete. The EPS concrete with fine silica fume showed the highest increase of split tensile strength (up to 25%). In addition, the failure mode of EPS concrete during the splitting was different from that of normal concrete. EPS concrete, especially that with steel fiber failed gradually instead of abruptly.

3.3. Shrinkage

Two of the most significant factors affecting the shrinkage of concrete are the degree of restraint by the aggregate, that is, its elastic properties and the volumetric proportion of the paste in the mix. The EPS beads offer little hindrance to the shrinkage of the paste [8]. Hence, as the volumetric proportion of the EPS is increased, the shrinkage would increase as well, which is shown in Fig. 5. At 90 days, the drying shrinkage of normal concrete was 630 microstrain. For EPS concrete, when the volume content of EPS was 55%, the drying shrinkage at 90 days

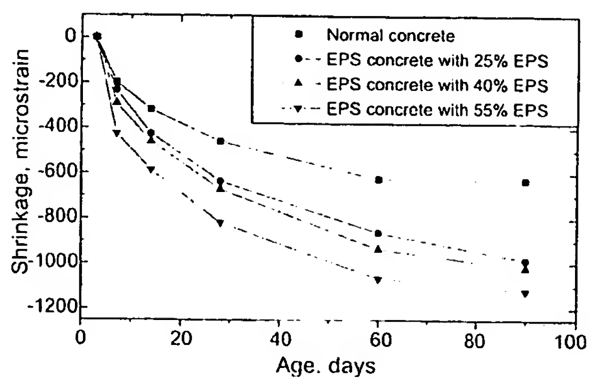

Fig. 5. Relationship between drying shrinkage strain of EPS concrete and reference concrete with age.

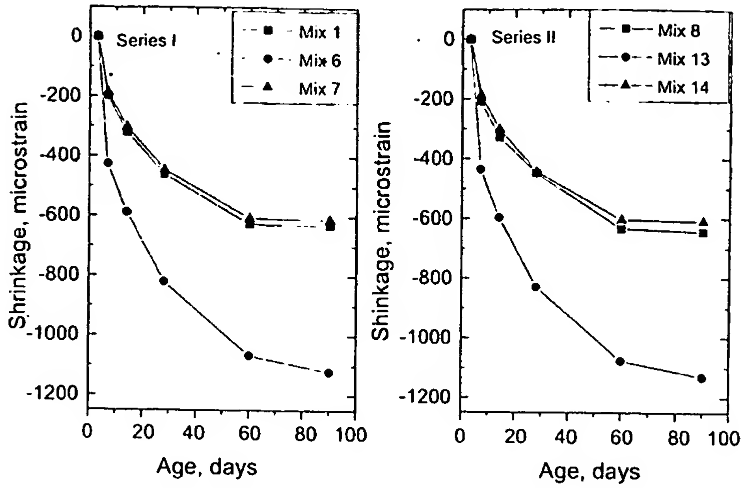

Fig. 6. Effect of steel fiber on the drying shrinkage strain of EPS concrete and reference concrete with age.

was up to 1121 microstrain, which indicated the disadvantage in the application of EPS.

The effect of steel fiber on the drying shrinkage of EPS concrete is shown in Fig. 6. It can be seen that steel fiber improved the drying shrinkage of EPS concrete greatly. Even for EPS concrete with 55% of volume content of EPS, the drying shrinkage at 90 days was 610 microstrain, which was less than that of normal concrete.

4. Conclusion

1. A technique similar with sand-wrapping to make EPS concrete enables good workability and easy compaction and finishability, without adding special bonding agents. The compressive strength of EPS concrete can be up to 10–25 MPa, at densities from about 800–1800 kg/m^3 of density.
2. Fine silica fume can increase the strength of EPS concrete (at most 15%) by improving the dispersion of EPS beads in the cement matrix and then the bonding between EPS beads and cement paste.
3. Steel fibers can significantly increase the split tensile strength of EPS concrete and improve its shrinkage resistance properties.
4. The mechanical and shrinkage properties can be optimized by adding fine silica fume and steel fibers at appropriate contents.

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PHYSICAL PROPERTIES OF EPS

EPS Physical Prop

Physical Properties of EPS

Specification Reference (ASTM-C578-95)				Type I (1#)	Type VIII (1 1/4#)	Type II (1 1/2#)	Type IX (2#)
Property:	*Units*	*ASTM Test*					
Density, Min.	(pcf)	C303 or D1622		0.90	1.15	1.35	1.80
Thermal Conductivity "K Factor"	BTU/(hr)(sqft)(°F/in)	C177 or C518	@ 25 °F	0.238	0.227	0.217	0.208
			@ 40 °F	0.250	0.238	0.227	0.217
			@ 75 °F	0.277	0.263	0.250	0.238
Thermal Resistance "R Value"	One inch thickness	C177 or C518	@ 25 °F	4.20	4.40	4.60	4.80
			@ 40 °F	4.00	4.20	4.40	4.60
			@ 75 °F	3.60	3.80	4.00	4.20

Strength Properties				Type I (1#)	Type VIII (1 1/4#)	Type II (1 1/2#)	Type IX (2#)
Property:	*Units*	*ASTM Test*					
Compressive @ xx% deflection	psi	D1621	@ 1/2%	3.5	4.3	6.0	8.0
			@ 1%	7.0	8.5	12.0	16.0
			@ 5%	8.0	11.0	12.0	20.0
			@ 10%	10.0	13.0	15.0	25.0
Flexural	psi	C203		25	32	40	55
Tensile	psi	D1623		16	17	18	23
Shear	psi	D732		18	23	26	33
Shear Modulus	psi	—		280	370	460	600
Modulus of Elasticity	psi	—		180	250	320	460
Allowable Compressive Stress	psi	.	Long-Term Load	2.1	3.3	4.5	7.0
			Short-Term Load	4.0	5.0	5.9	9.1
			Rolling Loads	8.0	10.0	11.8	18.2
Young's modulus	psi	.	.	573	739	1000	1449
Modulus of Subgrade Reaction	[k],pci	.	.	200	240	280	460
Poisson's Ratio	[v]	.	.	.086	.103	.126	.165
Coefficient of Friction	.	.	.	0.5-0.7	0.5-0.7	0.5-0.7	0.5-0.7

Moisture Resistance				Type I (1#)	Type VIII (1 1/4#)	Type II (1 1/2#)	Type IX (2#)
Property:	*Units*	*ASTM Test*					
Water Vapor Permeance, max. perm.	ng/Pa•s•m²	E 96	.	5.0	3.5	3.5	2.0
Absorption by Volume, max.	%	C272	.	< 4.0	< 3.0	< 3.0	< 2.0

Capillarity	—	—	.	None	None	None	None
Buoyancy	lbs/ft^3	.	.	60	60	60	60

Other Properties				Type I (1#)	Type VIII (1 1/4#)	Type II (1 1/2#)	Type IX (2#)
Property:	*Units*	*ASTM Test*					
Coeff. of Thermal Expansion	in./(in) (°F)	D696	.	0.000035	0.000035	0.000035	0.000035
Max. Service Temperature	°F	—	Long-Term	167	167	167	167
			Intermittent	180	180	180	180
Flame Spread max. 6"		UL® (BRYX)		20	20	20	20
Smoke Development		UL® (BRYX)		300	300	300	300

All values based on data from Huntsman Chemical Corporation, Styrochem International, NOVA Chemical Corporation and BASF Corporation.

Federal Trade Commision Ruling: Use the 75 F R-Value when calculating R-Values for residential construction.

Design Considerations:

- **DO NOT COMPARE** polyisocyanurate conditioned R-Values by RIC-TIMA and PIMA to EPS R-Values by ASTM C-578.
- **ASK for a 20 year 100% R-Value Warranty.**
- **Flammability:** Like many construction materials, EPS is combustible. It should not be exposed to flame or other ignition sources. Current model building code requirements should be met for adequate protection or seperation from occupied areas.
- **Water Absorption Properties:** EPS water absorption is low. Moisture takes the path of least resistance and travels around individual beads rather than through them; the non-interconnecting cell structure prevents capillary absorption.
- **Water Vapor Transmission:** EPS has low permeability but is not considered a vapor barrier.

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MatWeb.com, The Online Materials Database

ALBIS MIPS 05A13A Natural, Unreinforced

Subcategory: Polymer; Polystyrene; Thermoplastic

Close Analogs:

This product is no longer listed in ALBIS Plastic Corporation's list of available products - October 2002.

Key Words: Polystyrene; Albis Plastics Corporation

Material Notes:
Amorphous Medium Impact Polystyrene (MIPS)

Characteristics: FDA Compliant: Natural Whiteness, High Melt Flow, Fast Cycling

Applications: Thin Walled Parts, Scale Models, Toys, Containers, Color Concentrate Carrier

Processing: Injection Molding (Melt Temperature: 375-540°F, Mold Temperature: 40-175°F)

Data supplied by Albis Plastics Corporation.

Physical Properties	**Metric**	**English**	**Comments**
Melt Flow	13 g/10 min	13 g/10 min	(200°C/5.0 kg); ASTM D1238
Mechanical Properties			
Tensile Strength at Break	24.8 MPa	3600 psi	ASTM D638
Elongation at Break	40 %	40 %	ASTM D638
Modulus of Elasticity	2.21 GPa	321 ksi	ASTM D638
Flexural Modulus	2.55 GPa	370 ksi	ASTM D790
Flexural Yield Strength	46.9 MPa	6800 psi	ASTM D790
Izod Impact, Notched	0.69 J/cm	1.29 ft-lb/in	ASTM D256
Thermal Properties			
Deflection Temperature at 1.8 MPa (264 psi)	88 °C	190 °F	ASTM D648
Vicat Softening Point	93 °C	199 °F	ASTM D1525
Optical Properties			
Gloss	90 %	90 %	60°; ASTM D523
Processing Properties			
Processing Temperature	191 - 282 °C	376 - 540 °F	Injection melt temp
Mold Temperature	4 - 79 °C	39.2 - 174 °F	